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RETIREMENT OF MR M. H. FREEMAN, O.B.E.

Mr M. H. Freeman, Deputy Director (Forecasting), retired from the Meteorological Office on 31 December 1975, a few months before his sixtieth birthday. He graduated from King's College, London in 1937, with a first class honours degree in mathematics and, after obtaining a teaching diploma, taught until the early days of the Second World War when in April 1940 he joined the Meteorological Office as a Temporary Forecaster. Following initial training he was posted to Headquarters No. 11 Group Royal Air Force at Uxbridge in August 1940 at the height of the Battle of Britain and he remained in that busy and responsible forecast office for six years. He obtained his Master of Science degree in Meteorology at Imperial College, London in 1944.

After the war Mr Freeman was established as a Senior Scientific Officer and served for two years in charge of the forecast office in Khartoum. On return to England in 1948 he had a short spell at the newly created London Airport at Heathrow followed by over three years in the Civil Aviation Branch at Headquarters. In 1953 he was promoted to Principal Scientific Officer and was meteorological observer at the first tests of the British atomic bomb in Australia. He had short periods at Bawtry and as a senior forecaster in the Central Forecasting Office at Dunstable and was then assigned as Meteorologist for the tests of the hydrogen bomb at Christmas Island in 1957; his achievements in this post were recognized by his appointment as an Officer of the Order of the British Empire in the following year.

Between 1958 and 1963 Mr Freeman was engaged in research into forecasting, first in the Synoptic Research Branch and later in the Techniques and Training Branch. After a few months on the Senior Forecaster roster in the Central Forecasting Office, by now at Bracknell, he was promoted in 1963 to the post of Assistant Director (Synoptic Climatology) where one of his early tasks was the issue for the first time to the general public of the *Monthly Weather Survey and Prospects.*

In 1966 he became Chief Meteorological Officer at London (Heathrow) Airport, returning to Headquarters, Bracknell, in 1970, as Assistant Director (Public Services). In 1971 he was transferred as Assistant Director (Special Investigations) and on promotion in 1972 he became Deputy Director (Communications and Computing), becoming Deputy Director (Forecasting) in September 1973.

Howarth Freeman has always had a practical, logical bent and the Office recognized this and made good use of his special talents. He was a sound and successful synoptic forecaster for many years and was specially chosen to cope with the new meteorological problems associated with the atomic and hydrogen bombs. He introduced computer-aided forecasts for aviation purposes when he was at Heathrow in the late sixties and later he made a special survey of the forecasting service for the Royal Air Force which led to considerable streamlining. He was never afraid of change and was always seeking to improve. He was widely known within the Office and his cheerful friendly personality will be missed by his colleagues.

We all wish him and Mrs Freeman a long and happy retirement.

J. K. BANNON

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COMPARISON OF THE CATCH OF GROUND-LEVEL AND CANOPY-LEVEL RAIN-GAUGES IN THE UPPER SEVERN EXPERIMENTAL CATCHMENT

By ANNA J. NEWSON and R. T. CLARKE
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SUMMARY

This note describes the results of statistical analyses comparing the monthly catch of ground-level rain-gauges with that of canopy-level gauges in the Institute of Hydrology's experimental catchment in the headwaters of the River Severn. The results suggest that, for all months free of snowfall, there is no evidence that the canopy-level gauges catch significantly less than those at ground level, as had been feared; for months when an appreciable part of the precipitation fell as snow, however, there was evidence that canopy-level gauges caught significantly less than ground-level gauges.

INTRODUCTION

The investigation by the Institute of Hydrology, currently in progress on the headwaters of the Wye and Severn catchments in mid Wales, into the hydrological differences between coniferous forest and hill pasture, required a measurement of the precipitation over the forest canopy of the Severn for comparison with that over the hill pasture of the Wye; about one-third of the Severn is also unforested. For the Wye, and for the unforested area of the Severn, precipitation was measured using Octapent (Mk 2A) gauges installed at ground level in square pits, surrounded by a 1·33-metre square plastic grid to prevent splash, and set with the gauge orifice in the tangent plane to the slope (Rodda, 1968). For the forested part of the Severn, the gauges chosen were mast-top canopy-level gauges, each consisting of a sheet-copper funnel with the standard 5-in (127·0-mm) diameter with a slant length of 3·5 in (88·9 mm) feeding into a copper tube ½ in (12·7 mm) in diameter, mounted with the funnel rim horizontal on a vertical mast. Polythene tubing connects the funnel to the base collector, a modified period gauge with firmly fitting lid. All gauges are read monthly. The mast-top gauges are installed in the forest with their funnels at mean canopy level or above. The trees (mainly Sitka spruce) range in height from 3 m to 16 m.

The rain-gauges in the Severn and Wye networks were distributed according to the proportion of catchment area falling into categories or 'domains', delimited by four divisions of altitude, four of aspect and three of slope. For the purposes of this note the Severn catchment only need be considered; the divisions of altitude, aspect and slope used to delimit the domains are as follows:

Altitude (metres)	320–424 (code A)
	425–529 (code B)
	530–634 (code C)
	635–740 (code D)
Slope (degrees)	0–9 (code 1)
	10–19 (code 2)
	≥20 (code 3)
Aspect	North-easterly (code W)
	South-easterly (code X)
	South-westerly (code Y)
	North-westerly (code Z)

Of the 116 homogeneous elements of area into which the Severn was divided (making up 32 different combinations of domain criteria out of a possible 48) only those contributing more than 2 per cent of the total area of the catchment contain a gauge placed at random. There are 18 period gauges in all in the Severn network, representing 17 domain combinations; 7 are at ground level and 11 at canopy level. The numbers of ground-level and canopy-level gauges in each altitude division are as follows:

	Altitude division				
	A	B	C	D	Total
	Number of gauges				
Ground level	0	2	2	3	7
Canopy level	5	3	3	0	11
Total	5	5	5	3	18

ANALYSIS

Earlier analysis (Clarke *et alii*, 1975) of the catch recorded by monthly storage gauges on the Wye and Severn had shown that catch varied significantly with altitude division (gauges in the higher-altitude divisions recording greater falls than those in lower altitude divisions); there was no evidence, however, that catches by gauges in different slope divisions, or in different aspect divisions, differed significantly. For the analysis described in this note, therefore, altitude effects were retained in the statistical model, but aspect and slope effects were assumed negligible.

The statistical model used was as follows. Consider the catch in a particular month by a gauge in altitude division i (where i = A, B, C or D). If μ is the true areal mean precipitation for the entire catchment, the catch by the gauge in division i will deviate from μ by an amount a_i which measures the extent to which gauges in that altitude division tend to catch more (or less) than the true areal mean. Clearly the sum of the a_i over all the gauges in the network must be zero, because the areal mean is μ. The gauge under consideration may be either a ground-level gauge or a canopy-level gauge, and if the possibility of differential catch is admitted, a term l_j must be included with $j = 1, 2$ (l_1 is the deviation from the areal mean μ appropriate to ground-level gauges, whilst l_2 is that appropriate to canopy-level gauges). The quantities l_j therefore

measure the differential effect of gauge 'level'; as before, the sum of the l_j over all the gauges in the network must be zero. The effects on catch of altitude differences between ground-level and canopy-level gauges in the same altitude class (A, B, C or D) are assumed negligible. Finally, if there are several gauges in a particular altitude division all of which are, say, at ground level, then the catch by the kth gauge (y_{ijk}) will deviate from $\mu + a_i + l_j$ by a quantity ϵ_{ijk} which is regarded as a random variable. The complete model is therefore

$$y_{ijk} = \mu + a_i + l_j + \epsilon_{ijk}\ (i = \text{A, B, C, D};\ j = 1,2)$$
$$\Sigma a_i = \Sigma l_j = 0, \text{ where summation is over all gauges in the network.}$$

Linear statistical theory was used to test the hypothesis that catches by ground-level and canopy-level gauges do not differ, except for random variation. (In the terminology, the null hypothesis is given by H_0: $l_1 = l_2 = 0$, to be tested against the alternative hypothesis H_1: $l_1, l_2 \neq 0$). The calculation is best set out in tabular form in which the total sum of squares of deviations from the estimated arithmetic mean $\bar{\mu}$ for the whole catchment is divided into three components: one corresponding to differences between altitude divisions, ignoring the effects of differences between levels; another corresponding to differences between levels, eliminating the effects of differences between altitude divisions; and a third yielding an estimate of the variance of residuals ϵ_{ijk}. The analysis-of-variance table therefore appears as follows:

		d.f.
(A)	Between altitude divisions (ignoring levels)	3
(L)	Between levels (eliminating altitude effects)	1
	Residual	13
	Total	17

The null hypothesis of no difference between levels is tested by comparing the ratio (mean square between levels, eliminating altitude effects/residual mean square) with tabulated values of the F-statistic with 1 and 13 degrees of freedom (d.f.).

In addition, the statistical model used above ($y_{ijk} = \mu + a_i + l_j + \epsilon_{ijk}$) was modified to test whether the differences in catch between ground-level and canopy-level gauges varied between altitude divisions (i.e. whether a significant interaction existed between altitude and level). Since the lowest altitude division, A, contained no ground-level gauge and the highest altitude division, D, contained no canopy-level gauge, the analysis was confined to altitude divisions B and C. The modified model becomes

$$y_{ijk} = \mu + a_i + l_j + (al)_{ij} + \epsilon_{ijk};$$

where a_i ($i = 1,2$) and l_j ($j = 1,2$) are constants measuring the altitude and level effects respectively, and the interaction terms $(al)_{ij}$ measure the extent to which level differences vary with altitude. As before, the null hypothesis H_0: $(al)_{ij} = 0$ for all i,j was tested against the alternative H_1: $(al)_{ij} \neq 0$ by means of a variance ratio test using an analysis of variance table. Since there were two ground-level gauges, and three canopy-level gauges, in each of the altitude divisions B and C, the analysis of variance is that appropriate to a two-by-two classification (level times altitude) with proportional numbers in

the sub-classes; for any one month, therefore, the total variation amongst the ten gauges was divided as follows:

		d.f.
(A)	Between altitude divisions	1
(L)	Between gauge levels	1
(AL)	Interaction	1
	Residual	6
	Total	9

The test for the hypothesis of no interaction is made by comparing the variance ratio (interaction mean square)/(residual mean square) with tabulated values for 1 and 6 degrees of freedom.

RESULTS

Table I shows the values of the 'level' constants l_1,l_2 (free from altitude effects) obtained month by month for the period April 1971–March 1973, together with the arithmetic mean for all 18 gauges. In 13 of the 24 months, ground-level gauges caught more than the overall mean (since the values of l_1 were positive in 13 months of the 24); in the remaining 11 months they caught less. On average, over all 24 months, ground-level gauges caught 2·8 mm more than the monthly mean (174·4 mm) and the canopy-level gauges caught 1·8 mm less

TABLE I—PARAMETERS l_1,l_2 REPRESENTING THE DIFFERENCE BETWEEN GROUND-LEVEL AND CANOPY-LEVEL GAUGE CATCH, APRIL 1971–MARCH 1973

	Mean, all gauges	Ground level (l_1) *millimetres*	Canopy level (l_2)	Snow days, Moel Cynnedd†
Apr. 1971	71·2	+0·8	−0·5	0
May 1971	75·2	+2·1	−1·3	0
June 1971	192·4	+2·4	−1·6	0
July 1971	71·1	+1·2	−0·7	0
Aug. 1971	217·8	−1·3	+0·8	0
Sept. 1971	89·7	+1·5	−1·0	0
Oct. 1971	211·2	+6·9	−4·4	0
Nov. 1971	307·9	+8·9	−5·7	7
Dec. 1971	127·9	−0·6	+0·4	3
Jan. 1972	227·6	+10·1	−6·4	8
Feb. 1972	145·9	+18·6*	−11·8*	6
Mar. 1972	213·2	+21·1*	−13·4*	3
Apr. 1972	301·2	+18·8	−12·0	0
May 1972	145·8	−6·5	+4·1	0
June 1972	198·1	−15·9	+10·1	0
July 1972	141·0	−6·4	+4·1	0
Aug. 1972	123·8	−5·0	+3·2	0
Sept. 1972	62·0	−2·4	+1·5	0
Oct. 1972	81·1	−1·6	+1·0	0
Nov. 1972	328·5	−3·5	+2·2	1
Dec. 1972	254·8	−5·5	+3·5	1
Jan. 1973	176·4	+5·7	−3·6	4
Feb. 1973	283·4	+26·7*	−17·0*	9
Mar. 1973	138·6	−8·4	+5·4	1
Overall mean	174·4	+2·8	−1·8	
Mean, months when snow fell	220·4(10)	+7·3	−4·6	
Mean, months when no snow fell	141·5(14)	−0·4	+0·2	

* Denotes statistical significance ($P < 0·05$). † National Grid Reference SN 843877.

($7 \times 2{\cdot}8 + 11 \times -1{\cdot}8 = 0$, apart from rounding error). Because no test for the significance of the altitude effects is possible using the analysis at present under discussion, the altitude constants a_A, a_B, a_C, a_D are not set out in Table I. This table also shows that significant ($P < 0{\cdot}05$) departures from zero of the level constants, l_1 and l_2, occurred in only 3 months of the 24 (February and March 1972, February 1973). All three were months when snow fell at Moel Cynnedd, a daily meteorological station in the Severn catchment: Table I shows the number of days on which snow fell there. If means are taken over all months when snow fell, gauges at ground level caught 7·3 mm more precipitation over a month than the mean for all gauges and those at canopy level about 4·6 mm less (Table I). Differences between ground-level and canopy-level gauges were much less evident in snow-free months when, on average, ground-level gauges caught about 0·4 mm less and canopy-level gauges about 0·2 mm more, than the mean for all gauges.

Results of the second part of the analysis, which had as its objective a test of whether differences between catches of ground-level and canopy-level gauges varied with altitude, are shown in Table II. A significant interaction was found

TABLE II—MEAN SQUARES FROM ANALYSIS OF VARIANCE TABLES FOR TESTING SIGNIFICANCE OF 'INTERACTION' BETWEEN ALTITUDE AND GAUGE-LEVEL, APRIL 1971–MARCH 1973

	d.f.	April 71	May 71	June 71	July 71	Aug. 71	Sept. 71
A	1	4·90	103·68*	1582·56	264·20	1020·10	370·88*
L	1	4·48	27·61	38·24	8·44	10·17	15·20
AL	1	11·27	11·35	176·47	34·81	19·84	0·05
Residual	6	35·88	11·05	497·54	49·57	237·60	57·45
Mean		71·48	76·44	201·48	72·20	222·96	93·49
CV		8·4%	4·3%	11·1%	9·8%	6·9%	8·1%

	d.f.	Oct. 71	Nov. 71	Dec. 71	Jan. 72	Feb. 72	Mar. 72
A	1	138·38	208·85	0·48	1904·40	851·93	372·10
L	1	306·00	512·75	2·20	656·70	2225·29*	2862·12*
AL	1	505·18	17·50	38·56	2350·00*	846·75	620·82
Residual	6	626·87	1156·61	197·40	214·92	279·47	288·32
Mean		213·80	309·03	130·00	224·00	127·23	202·28
CV		11·7%	11·0%	10·8%	6·5%	13·1%	8·4%

	d.f.	April 72	May 72	June 72	July 72	Aug. 72	Sept. 72
A	1	8323·23*	165·65	302·50	571·54	197·14	26·57
L	1	2266·89	268·82	1619·28	265·02	160·07	35·88
AL	1	317·41	17·71	456·50	13·35	3·36	9·13
Residual	6	1099·63	181·97	695·66	168·48	83·05	6·32
Mean		308·31	147·55	205·86	146·38	128·00	62·87
CV		10·8%	9·1%	12·8%	8·9%	7·1%	4·0%

	d.f.	Oct. 72	Nov. 72	Dec. 72	Jan. 73	Feb. 73	Mar. 73
A	1	384·40*	4481·69*	112·90	535·82	232·32	1·68
L	1	15·71	79·12	197·29	211·31	4592·00*	459·27
AL	1	4·54	1·39	212·06	80·27	180·61	98·30
Residual	6	34·18	529·88	564·54	905·39	449·58	399·82
Mean		82·26	333·07	263·44	186·42	284·48	137·85
CV		7·1%	6·9%	9·0%	16·1%	7·4%	14·5%

* Denotes statistical significance $P < 0{\cdot}05$.

Note. An explanation of A, L and AL is given in the text (see page 4).
CV is the coefficient of variation, d.f. means degrees of freedom.

only in January 1972. This could well be due to chance: when a large number of significance tests are made at the $P = 0{\cdot}05$ significance level, approximately one test in twenty will suggest that real differences exist even when this is known to be false. Here, we have found but one significant interaction in 24 independent tests, a proportion agreeing well with what could be expected if no interaction existed. It would not be incorrect to conclude, therefore, that such interaction as does exist between level and altitude is probably small.

Discussion

The difficulties associated with measurement of precipitation over a forest have long been recognized (Mill, 1900) and a comprehensive review of the problem has been given by Penman (1963). In a more recent contribution, Clarkson (1973) studied the performance of a tulip-shaped rain-gauge funnel mounted on a 10-m mast, concluding that it collected 98·4 per cent of the catch of a standard Mk 2 rain-gauge nearby. The results of the present analysis, comparing the catches of two types of rain-gauge, show no evidence that canopy-level gauges caught significantly less than ground-level gauges in months free of snowfall. For months when an appreciable proportion of the precipitation fell as snow, however, there was evidence that the catch of canopy-level gauges differed from that of ground-level gauges; this may be because turbulence caused the canopy-level gauges to undercatch snowfall, or because snow drifting into the funnels of ground-level gauges caused them to overcatch. For water-balance calculations, therefore, the Institute is now measuring the input of precipitation as snowfall by means of ground-based photogrammetry (to give snow depth) together with snow-core sampling (to give snow density).

When comparing the effects of alternative land uses on the water balance, the problem of sampling precipitation over a range of topographic locations is frequently encountered; the problem is especially severe where the land-use under investigation is dense forest with few large clearings for conventional ground-based gauges. The above conclusions give room for optimism regarding the use of mast-top, canopy-level gauges for the measurement of precipitation over forest in those conditions where snowfall is not a significant component of catchment input.

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551.553.12:551.588.2(411)

THE EFFECT OF TOPOGRAPHY ON SURFACE WIND

By D. M. GUNN and D. F. FURMAGE
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SUMMARY

Anemograph records from four valley stations in Scotland, where topography would be expected to influence materially the surface wind direction and speed, were studied in order to show the extent of such influence and whether a coherent pattern existed. Further, from these findings, an attempt was made to establish a method which might have general application in forecasting surface wind velocities in valleys.

INTRODUCTION

Ideally, an anemograph is exposed at a height of 10 metres above the ground in level, open terrain with no obstructions nearer than 200 metres in any direction. Although the immediate surroundings may satisfy these conditions, the surface wind can be affected by surrounding hills and valleys, particularly in mountainous areas such as those in Scotland.

For this study the records from anemographs on four sites where the topographical influence is considerable were used. Their locations are shown on the map in Figure 1 and details of the sites are given in Table I. Maps showing the local topography with contours at 500-ft (about 150-m) intervals are given in Figures 2 to 5. On each map a cross indicates the position of the anemograph.

TABLE I—DETAILS OF THE ANEMOGRAPH SITES

Station	National Grid Reference	Height of anemograph above MSL	above ground
		metres	
Tummel	NN 772590	161	16
Shin	NH 573974	24	10
Rannoch	NN 423575	306	17
Fort Augustus	NH 356085	58	16

Because of the absence of local obstructions to the wind flow, the effective height for each anemograph is equal to the actual height above the ground.

The period covered was May 1966 to April 1967 for all geostrophic wind directions plus May 1967 to April 1968 for winds between 010° and 170° in order to increase the number of samples with easterly winds.

METHOD

The surface wind recorded at each site was compared with the geostrophic wind over the local region obtained from charts of mean sea-level pressure. Only geostrophic winds of 20 knots or more were considered as it was thought that at low geostrophic speeds any relationship between the surface wind and geostrophic wind would be masked by local effects, such as anabatic and katabatic winds. The geostrophic wind velocity was measured from daily synoptic charts on a scale of 1:7½ M, prepared at three-hourly intervals. Directions were estimated to the nearest 10° and speeds to the nearest 2 knots, closer accuracy not being justified with the scale of working charts used. The mean hourly wind velocity recorded at the anemograph station in the hour preceding the chart time was taken as the surface wind. Occasionally, because

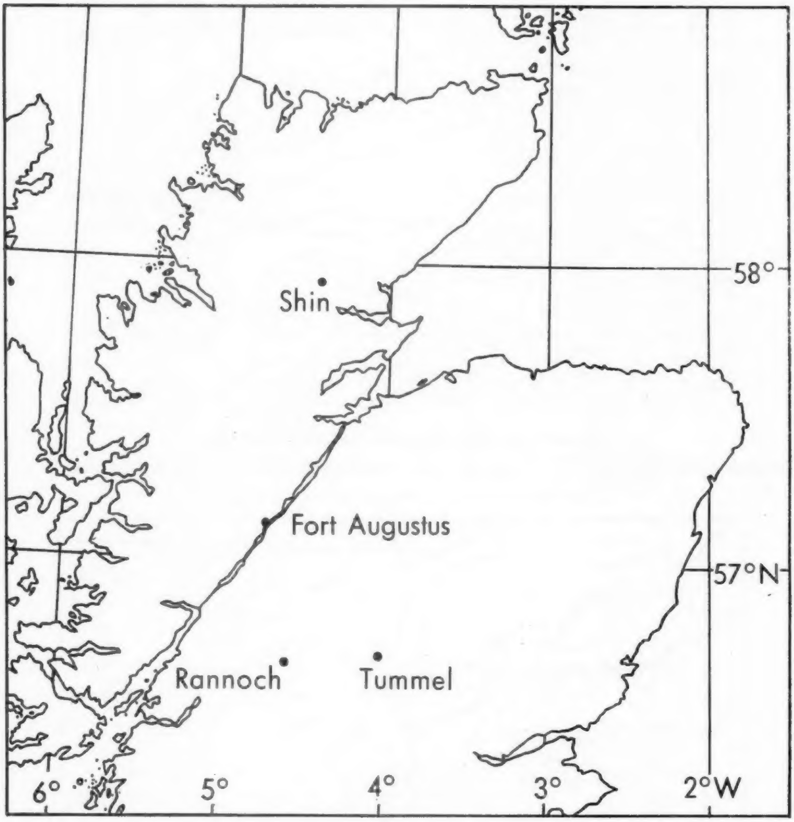

FIGURE 1—MAP SHOWING THE LOCATION OF STATIONS

there had been a change of direction in the surface wind during the hour, the mean value was considered unrepresentative and so was discarded. Values in the vicinity of fronts were also discarded.

ANALYSIS

For each station the geostrophic and surface winds were tabulated for each hour. Irrespective of the hour, the data were classified according to the 36 geostrophic wind direction sets and the following information extracted for each set:

(a) The ratio of the mean surface wind speed to the mean geostrophic wind speed and the standard deviation of this ratio.
(b) The mean and standard deviation of the surface wind direction.
(c) Three-term running means (covering an angle of 30°) of the ratio of mean surface wind to mean geostrophic wind speed.

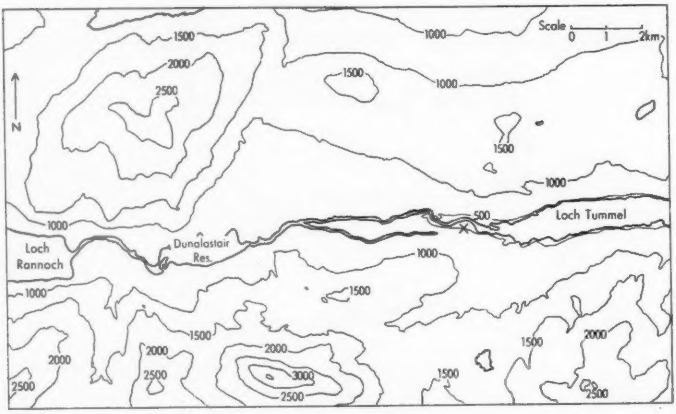

FIGURE 2—TOPOGRAPHY AROUND TUMMEL

Heights are in feet (1000 ft ≈ 305 m). The anemograph site is shown by a cross.

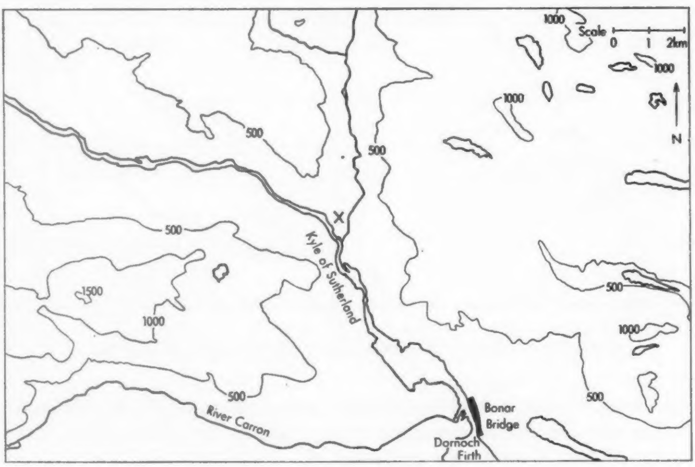

FIGURE 3—TOPOGRAPHY AROUND SHIN

See notes below Figure 2.

(d) Three-term running means (covering an angle of 30°) of the mean angle between the geostrophic and surface wind directions.

These results are shown graphically in Figures 6 to 9. The number of samples for each direction is entered on the curve (d) in each figure.

For each station the following information was determined:

(i) Backing of surface wind from geostrophic wind in the valley direction.

(ii) Geostrophic wind direction for minimum backing of surface wind.

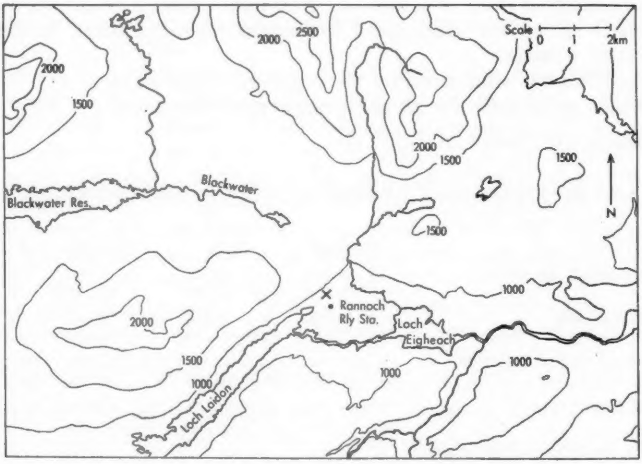

FIGURE 4—TOPOGRAPHY AROUND RANNOCH
See notes below Figure 2.

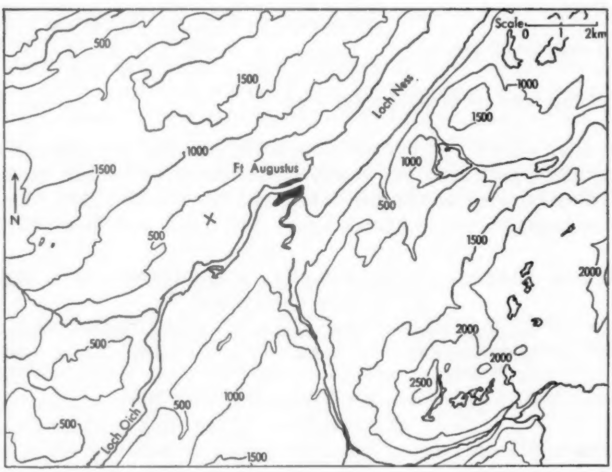

FIGURE 5—TOPOGRAPHY AROUND FORT AUGUSTUS
See notes below Figure 2.

(iii) Ratio of surface wind speed to geostrophic wind speed in the valley direction.
(iv) Geostrophic wind direction for maximum speed ratio.
(v) Backing of surface wind from geostrophic wind in the cross-valley direction.

(vi) Geostrophic wind direction for maximum backing of surface wind.
(vii) Ratio of surface wind speed to geostrophic wind speed in the cross-valley direction.
(viii) Geostrophic wind direction for minimum speed ratio.
(ix) Mean speed ratio for all geostrohpic wind directions.

These details are shown in Table II.

TABLE II—RELATIONSHIP OF SURFACE WIND TO GEOSTROPHIC WIND

	Tummel	Shin	Rannoch	Fort Augustus
Backing in valley direction	13° at 090° −1° at 270°	25° at 120° 26° at 300°	7° at 060° 0° at 240°	10° at 050° 1° at 230°
Minimum backing	9° at 100° −2° at 260°	17° at 100° 15° at 270°	7° at 060° −3° at 230°	2° at 020° −31° at 180°
Speed ratio in valley direction	15% at 090° 26% at 270°	34% at 120° 40% at 300°	49% at 060° 55% at 240°	35% at 050° 35% at 230°
Maximum speed ratio	28% at 140° 29% at 290°	36% at 130° 41% at 290°	50% at 070° 56% at 290°	35% at 050° 36% at 240°
Backing in the cross-valley direction	72° at 180° 64° at 360°	64° at 210° 62° at 030°	54° at 150° 47° at 330°	42° at 140° 77° at 320°
Maximum backing	73° at 170° 73° at 030°	64° at 210° 62° at 030°	54° at 150° 47° at 330°	56° at 110° 77° at 320°
Speed ratio in cross-valley direction	19% at 180° 24% at 360°	21% at 210° 23% at 030°	42% at 150° 46% at 330°	23% at 140° 21% at 320°
Minimum speed ratio	17% at 200° 13% at 080°	21% at 210° 21% at 040°	31% at 190° 36% at 010°	20% at 160° 16% at 350°
Mean speed ratio for all wind directions	21·5%	31·5%	42·0%	23·5%

Note. All directions are of geostrophic wind.

For the four sites a comparison was made between the average ratios of hourly maximum-gust speed to hourly mean speed for surface winds greater than 10 knots blowing across the valley and down the valley. The period covered was January 1973 to March 1974. The results are shown in Table III.

TABLE III—AVERAGE RATIOS OF HOURLY MEAN MAXIMUM GUST SPEED TO HOURLY MEAN SPEED

Station	Mean elevation of surrounding terrain	Cross-valley ratio	Down-valley ratio	Mean ratio over all directions
Tummel	4·6°	2·30	1·90	1·99
Shin	3·3°	1·95	2·07	1·96
Rannoch	1·7°	1·65	1·52	1·52
Fort Augustus	4·1°	2·05	1·78	1·83

Discussion

Because of friction at the earth's surface, the wind near the ground is reduced in speed and backed in direction when compared with the geostrophic wind. The reduction in speed and the amount of backing depend on a number of factors including the nature of the terrain, the geostrophic wind speed and the stability of the air (which may depend to some extent on wind direction). For geostrophic winds of 20 knots or more, the wind measured at 10 m above open level country is backed 20–25° from the geostrophic wind direction and the

ratio of the speed to that of the geostrophic wind is 0·4–0·5; in the absence of thermal wind effects these values do not vary much with geostrophic wind direction.

Figures 6–9 show how the presence of valleys distorts the flow, with the surface winds tending to blow along the direction of the valley. As might be expected from the topography, the effect is most pronounced at Fort Augustus. At this station the deviations between the directions of the geostrophic and surface wind vary from a backing of 80° to a veer of over 30° and with geostrophic wind directions from 180° to 320° the surface winds blow along the valley with very little deviation from its orientation of 230° (Figure 9 (b)). Tummel (Figure 6 (b)) also shows the funnelling effect very clearly with surface winds blowing quite steadily from 090° to 100° with all geostrophic wind directions from 090° to 180°. At Shin and Rannoch where the valleys are less well defined, the channelling is not so pronounced but clearly in evidence (Figures 7 (b) and 8 (b)).

The valley effect is also apparent in the ratios of surface wind speed to the geostrophic wind speed. Figures 6 (c)–9 (c) show that the ratio varies approximately twofold in the valleys under consideration, with maxima when the geostrophic wind directions are roughly in the valley directions and minima when geostrophic wind directions are mostly between 50° and 90° away from the valley directions. Exceptions to these generalizations occur, notably a minimum ratio at Tummel with a geostrophic wind direction of 080° which is almost the same as the orientation of the valley. The reasons for these discrepancies are probably to be found in the detail of local topography and in the sample of observations.

From Table 3 it can be seen that gustiness in cross-valley winds is higher than in along-valley winds at all stations except Shin, where the valley direction is least well defined. There is fair correlation between the average gust ratio and the mean elevation of the terrain around the anemometer site. The effect will of course be masked to an appreciable extent by local aspects of exposure and this appears to be the case at Shin where the down-valley ratio exceeds the cross-valley ratio.

Application to forecasting

Stability of the surface layer must affect the relationship between surface wind speed and direction and orographic features but it has been neglected in this study. Further work needs to be done on the combined effects of stability and topography. Also, local aspects of exposure might have considerable influence, particularly with lighter surface winds.

In spite of the shortcomings in the data, the results have sufficient coherence to suggest that some guidance can be given in forecasting winds in valleys. However, since the shapes of valleys vary so much, some simple parameter to compare one with another is required. One possible parameter is the mean elevation of the horizon around the site. This was determined for each of the four sites and the mean speed ratio for all wind directions plotted against it. The mean surface wind speeds at Tummel, Rannoch and Fort Augustus were adjusted to a common height of 10 metres by applying a factor of 0·9 to the mean of the recorded values. The result is shown in Figure 10. The ratios at the lower elevation seem a little high, perhaps because they are unduly

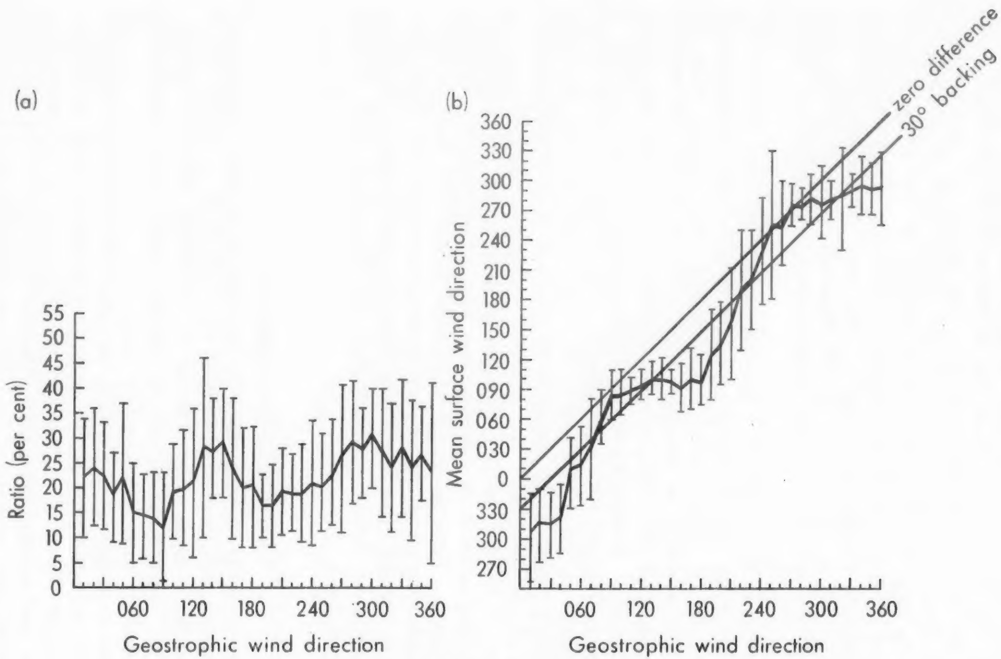

FIGURE 6—TUMMEL

(a) Variation of ratio of surface wind speed to geostrophic wind speed. Vertical lines show standard deviation of ratio.
(b) Variation of mean surface wind direction with geostrophic wind direction. Standard deviation shown by vertical lines. Lines of unit slope included to show theoretical variations for constant backings of 0 and 30°.

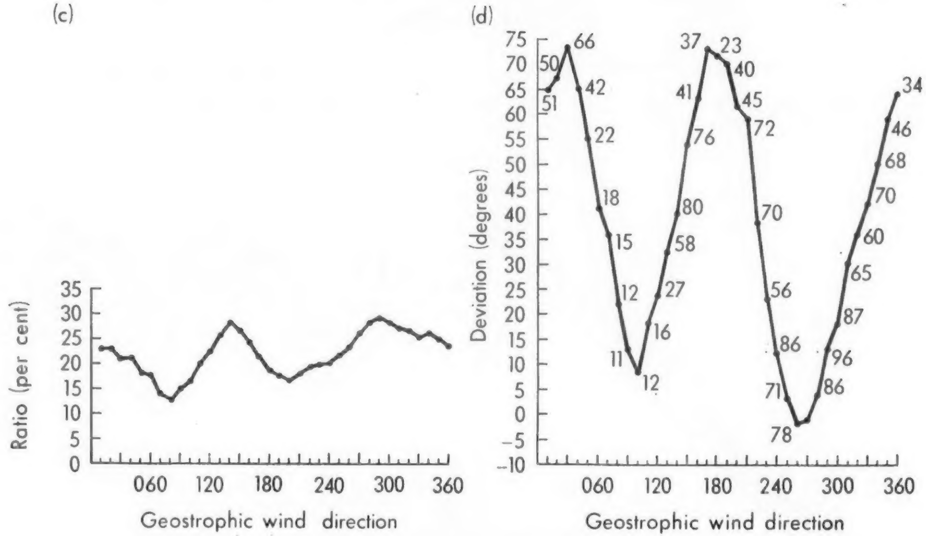

FIGURE 6—*continued*

(c) Variation of ratio of surface wind speed to geostrophic wind speed with geostrophic wind direction; 30° means centred on direction indicated.

(d) Deviation of mean surface wind direction from geostrophic wind direction (from 30° means centred on geostrophic wind direction). Number of samples shown for each direction. Positive values denote backing winds and negative values veering.

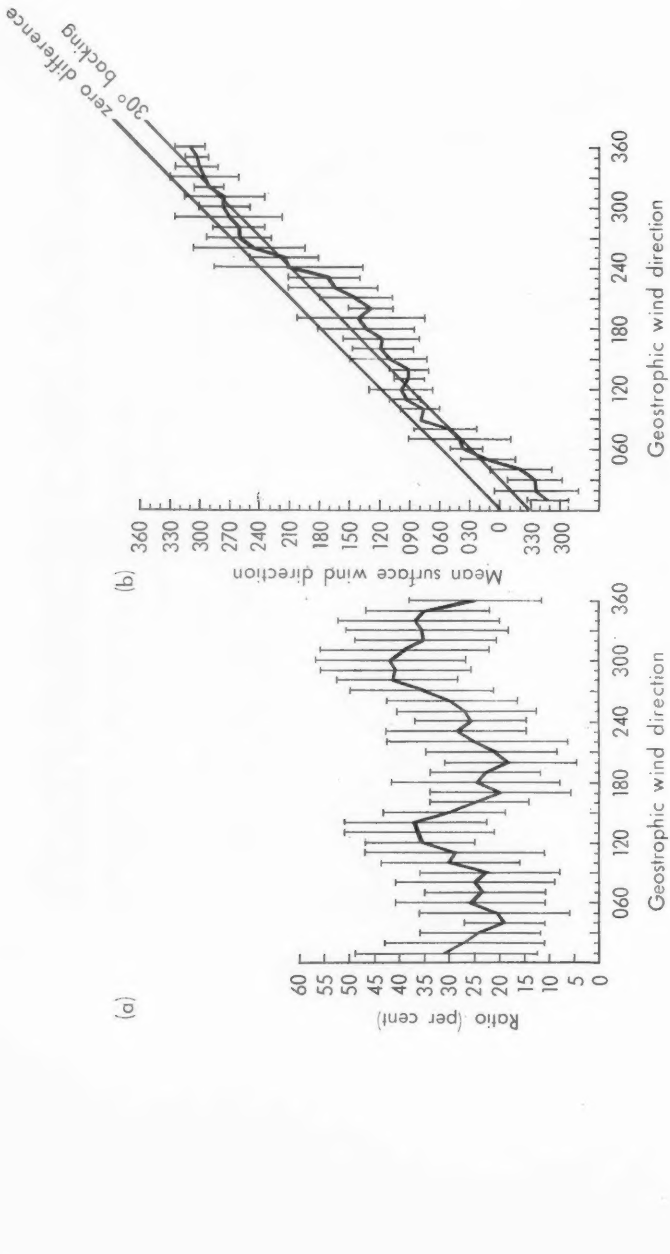

FIGURE 7—SHIN
See notes below Figure 6.

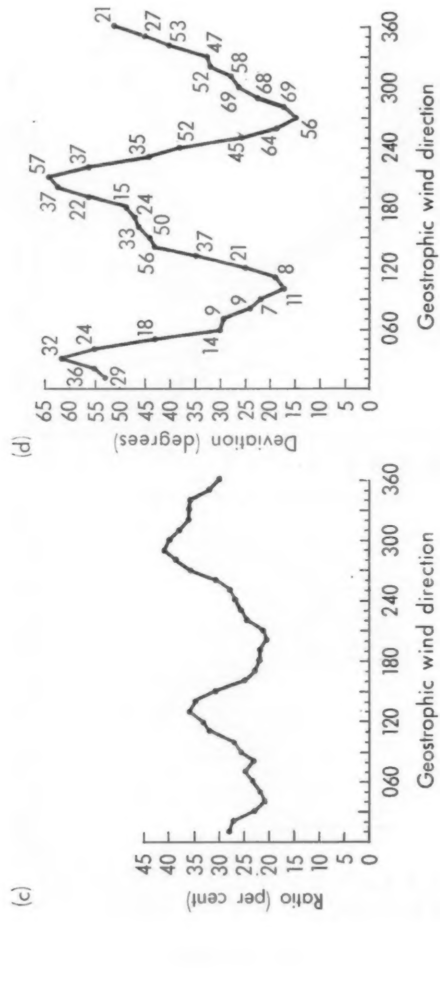

FIGURE 7—*continued*

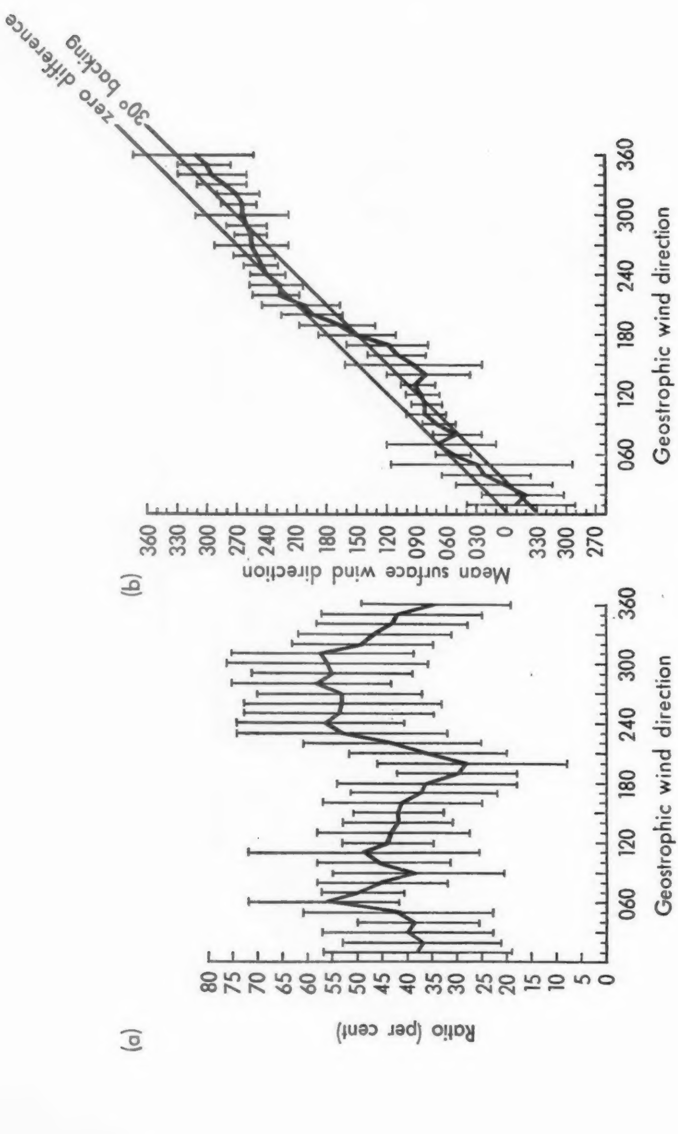

FIGURE 8—RANNOCH
See notes below Figure 6.

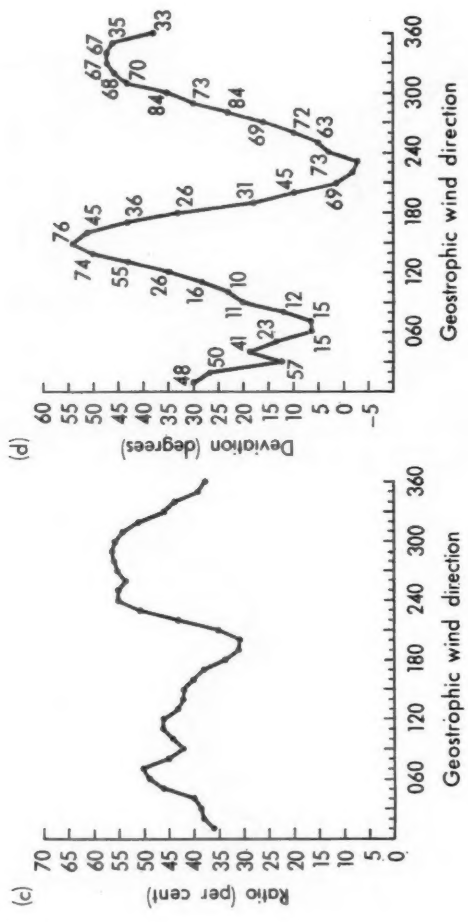

FIGURE 8—*continued*

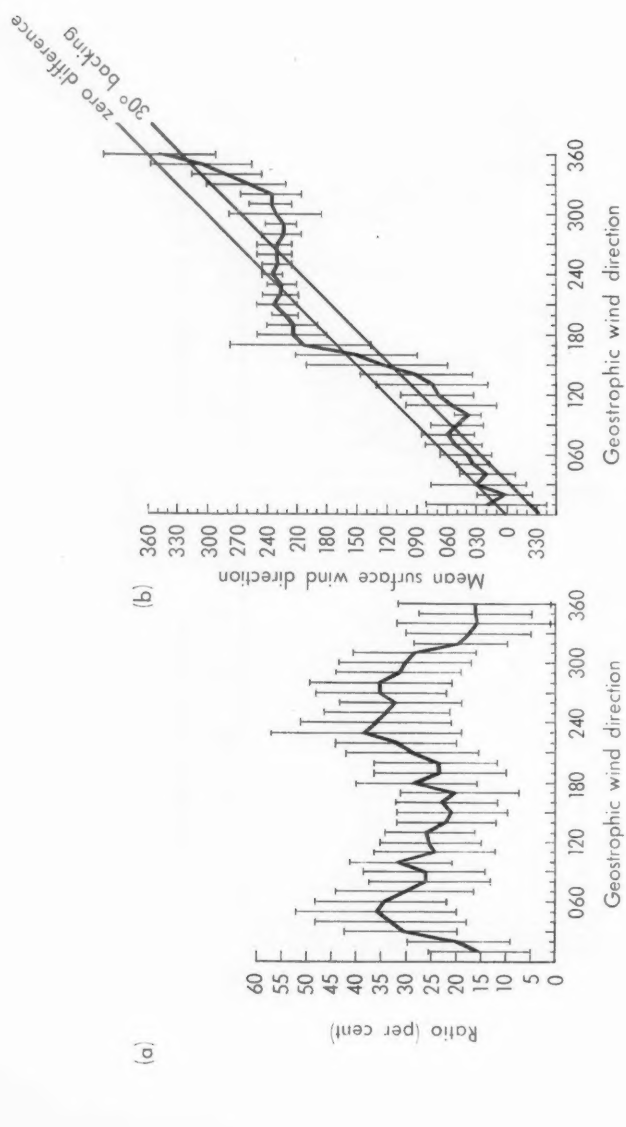

FIGURE 9—FORT AUGUSTUS
See notes below Figure 6.

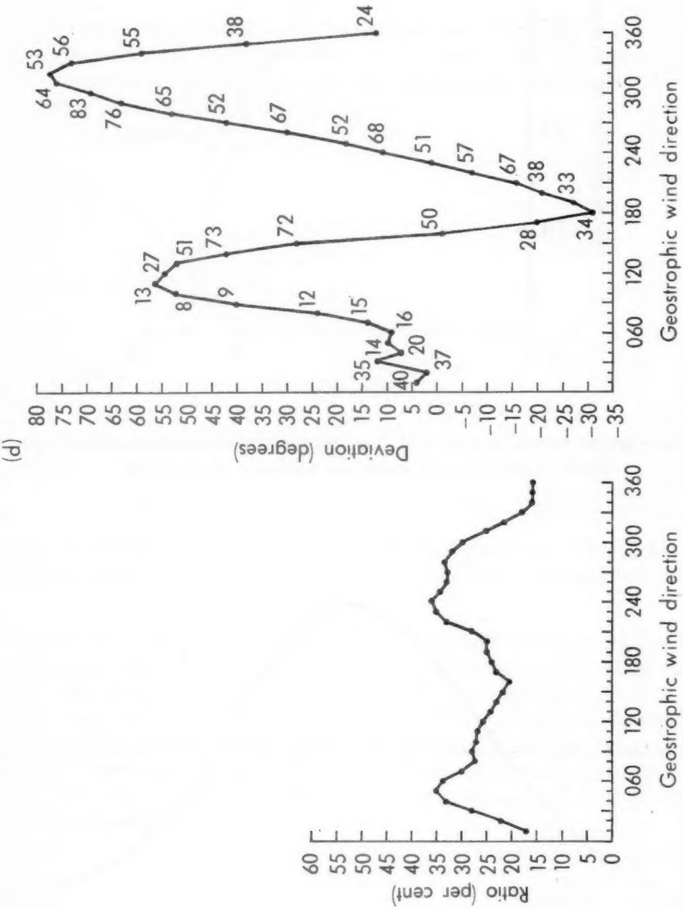

FIGURE 9—*continued*

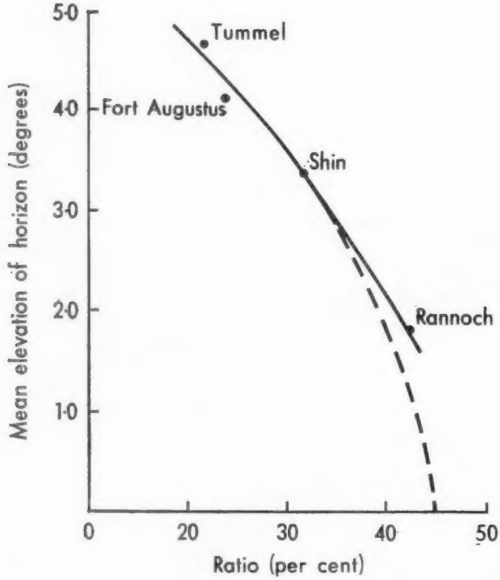

FIGURE 10—MEAN SPEED RATIO FOR ALL WIND DIRECTIONS PLOTTED AGAINST MEAN ELEVATION OF HORIZON FOR ALL FOUR SITES

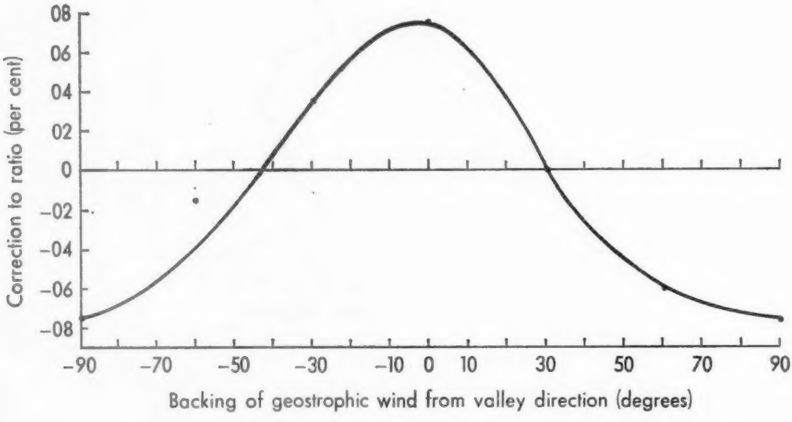

FIGURE 11—CORRECTIONS TO MEAN VALUES OF RATIO OF SURFACE WIND TO GEOSTROPHIC WIND FOR DIFFERENT VALUES OF DIRECTION OF GEOSTROPHIC WIND RELATIVE TO DIRECTION OF VALLEY

influenced by Rannoch which is in an elevated valley nearly 300 m above mean sea level and the dashed line which brings the curve to some value between 0·4 and 0·5 at zero elevation (which of course relates to open, level country) may be more realistic.

The differences between the mean speed ratio and the ratios found for different geostrophic wind directions were determined and the results are plotted in Figure 11. This is a composite diagram including the data from all four sites.

Mean values of the backing of the surface wind from the geostrophic wind were determined for the cross-valley geostrophic wind directions and then at 10° intervals over 180° through the down-valley direction. The results for all four sites are combined in Figure 12.

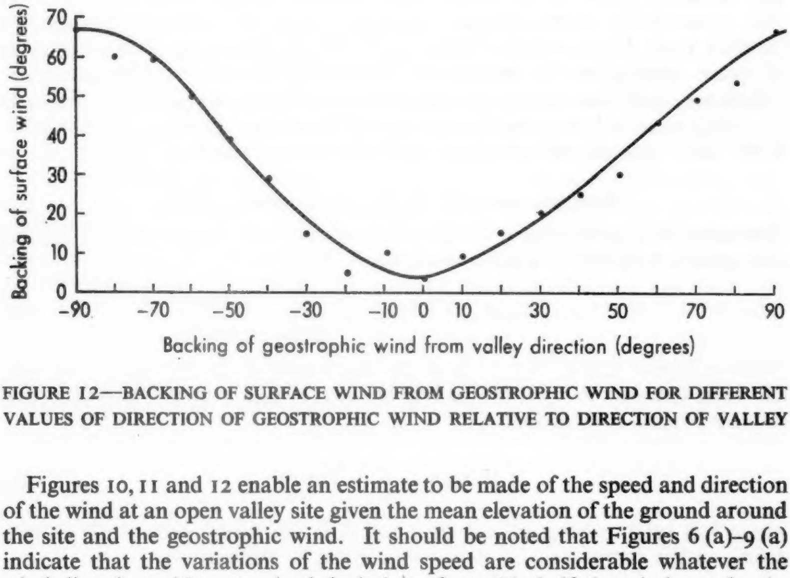

FIGURE 12—BACKING OF SURFACE WIND FROM GEOSTROPHIC WIND FOR DIFFERENT VALUES OF DIRECTION OF GEOSTROPHIC WIND RELATIVE TO DIRECTION OF VALLEY

Figures 10, 11 and 12 enable an estimate to be made of the speed and direction of the wind at an open valley site given the mean elevation of the ground around the site and the geostrophic wind. It should be noted that Figures 6 (a)–9 (a) indicate that the variations of the wind speed are considerable whatever the wind direction with a standard deviation of roughly half the wind speed. As for wind direction, Figures 6 (b)–9 (b) indicate that winds blowing along the valleys tend to be relatively steady but the direction of cross-valley winds fluctuates considerably.

551.509.329:551.510.62:621.371

FORECASTING THE DUCTING OF RADIO WAVES

By M. N. HOUGH
(Main Meteorological Office, Akrotiri, Cyprus)

SUMMARY

Results from atmospheric-refraction theory are used to prepare a diagram which can be used to assess the refractive state of the lower atmosphere from radiosonde ascents. The preparation of radio-wave propagation forecasts are then discussed using this diagram and general meteorological knowledge.

INTRODUCTION

Atmospheric conditions can markedly affect the propagation of radio waves. The refractive index of air varies with pressure, temperature and humidity, and occasionally meteorological conditions lead to unusual propagation (Booker, 1948; Meteorological Office, 1953). Stapley (1964) gave some examples of radar propagation in relation to weather at Gibraltar. Meteorological Offices are sometimes asked to provide forecasts of radio-propagation conditions on a daily basis and this note is an account of the method developed at Episkopi, which uses regularly plotted charts and radiosonde ascents.

METEOROLOGY AND RADIO-WAVE PROPAGATION

The radio refractive index n for air of pressure p mb, temperature T kelvins and specific humidity q g/kg is given by

$$(n-1).10^6 = \frac{77{\cdot}6}{T}\,p\left(1 - \frac{q}{4354} + \frac{4800q}{622T}\right) \quad \cdots \quad \cdots \quad (1)$$

(Meteorological Office, 1953) where the first constant on the right-hand side has been changed to 77·6 in accordance with Battan (1973). The modified refractive index M is defined by

$$M = (n + \frac{h}{R} - 1).10^6 \quad \cdots \quad \cdots \quad \cdots \quad (2)$$

where h is height above ground level and R is the earth's radius. With this definition the curvature of a radio ray relative to the earth is

$$-\ 10^{-6}\frac{\mathrm{d}M}{\mathrm{d}h} \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (3)$$

It has been found convenient to consider ray paths relative to the path in the standard radio atmosphere. This is the international standard atmosphere, but with a constant relative humidity of 80 per cent at all levels. In this standard radio atmosphere M increases with h. If M increases with h less than in this standard radio atmosphere, rays are bent away from the earth less than in the standard atmosphere. This condition is known as super-refraction and implies that the radio horizon is extended beyond the range expected with the standard atmosphere. However, if M increases with h more rapidly than standard, rays are bent away from the earth more than in the standard atmosphere. This condition is known as sub-refraction and is characterized by a radio horizon reduced from the standard.

A special case of super-refraction occurs when M decreases with height. In this case the radio waves are bent towards the earth and may be trapped in a layer known as a duct which results in a very marked extension of the radio horizon. It can be shown (Meteorological Office, 1953) that the condition for radio waves to be bent towards the earth and so form a duct is given by

$$1/(\partial T/\partial h)_{\text{CRIT}}\,\partial T/\partial h + 1/(\partial q/\partial h)_{\text{CRIT}}\,\partial q/\partial h \geqslant 1 \quad \ldots \quad \ldots \quad (4)$$

Here $(\partial T/\partial h)_{\text{CRIT}}$ and $(\partial q/\partial h)_{\text{CRIT}}$ are the critical gradients of temperature and humidity respectively. $(\partial T/\partial h)_{\text{CRIT}}$ is the minimum temperature gradient required to satisfy (4) when $\partial q/\partial h = 0$, with a similar definition for $(\partial q/\partial h)_{\text{CRIT}}$. For an atmosphere with $p = 1000$ mb, $T = 288$ kelvins and 80 per cent relative humidity $(\partial T/\partial h)_{\text{CRIT}}$ is $+0{\cdot}087$ kelvins/metre and $(\partial q/\partial h)_{\text{CRIT}}$ is $-0{\cdot}48$ g kg^{-1} (100 ft)$^{-1}$ ($-0{\cdot}016$ g kg^{-1} m^{-1}).

Meteorological situations associated with ducting

Gradients of temperature and humidity similar to or more than the critical values are common and the conditions in which they can be expected to occur can be broadly divided into advection, subsidence and radiation.

Advective situations are typically characterized by warm dry air passing over a colder, wet surface. For example when air from a desert area passes over the sea in summer the air takes up water by evaporation while heat is transferred to the sea from the air which produces a moist layer capped by a temperature inversion. This coincidence of temperature inversion and humidity lapse is very favourable for duct formation since both terms on the left-hand side of expression 4 are additive. The humidity term is often the larger since even an isothermal temperature gradient can reduce turbulence and allow large humidity gradients to build up. Another common advective situation exists in the sea-breeze when cool, moist air over the sea is drawn inland where the air is warmer and drier. The upper surface of the sea-breeze where it meets the land air is a region where suitable humidity and temperature gradients may form.

A different advective situation exists when cold dry air blows over a warmer, wet surface. Evaporation into the dry air produces a steep humidity lapse, so that despite the temperature lapse that is also set up, expression 4 is still satisfied and a duct is formed. Examples include dry Arctic air blowing over the warmer sea, or cold dry air behind a cold front which crosses land that has been wetted by heavy rain.

Subsidence inversions are commonly associated with anticyclones. The air becomes warmer as it subsides while the specific humidity is maintained at the value that existed before descent took place. In this way expression 4 is satisfied but often at a high level above the earth's surface. For radio transmitters near sea level these ducts are usually only important when the subsidence inversion is below about 2000 m while those above 4000 m can normally be ignored.

The formation of a nocturnal surface inversion over land areas when the sky is clear often produces large temperature gradients near the ground. Humidity gradients are usually small so that the temperature term dominates in expression 4. However, if the air is sufficiently moist for fog to form, mixing

occurs within the fog which reduces temperature gradients and the duct is likely to weaken. If the fog has a well-defined top, the hydrolapse may be sufficiently large to cause ducting.

Forecasting ducting conditions

The forecasting method developed at Episkopi makes use of an analysis based on the qualitative ideas mentioned above together with a rough numerical assessment based upon radiosonde ascents and inequality 4. A forecast of future ducting conditions is made using prognostic charts together with any reasonable qualitative changes.

(a) Inequality 4 is represented graphically (Meteorological Office, 1953) and Figure 1 shows this graph with axes suitable for use with tephigrams. The line AB shown as separating an area labelled 'ducting' from one labelled 'partial ducting' is equation 4 with the critical gradients corresponding to the standard radio atmosphere ($T = 15°C$, $p = 1000$ mb; relative humidity is 80 per cent). Higher in the atmosphere, at say $p = 800$ mb, the critical gradients are 0·8 of their values at 1000 mb, but the temperature is also lower, causing an increase in the critical temperature gradient, but a slight decrease in the critical humidity gradient.

In general then, the line AB should adequately represent most conditions between 1000 and 800 mb, which is the area of most interest in duct forecasting.

The area of 'partial ducting' has been introduced in Figure 1 to allow for inadequacies in radiosonde ascents. Owing to the rate of sampling, the radiosonde averages out much of the steep temperature and humidity gradients that exist. Many tephigrams show isothermal or weak inversion layers which, when plotted in Figure 1, fall above the line AB. Unless it is known with certainty that this is a true representation, it is better to say that ducting will take place in a limited number of directions, or over a restricted area, than to give a definite 'no'. The limit of the partial-ducting area is difficult to fix with precision since it depends upon where the sonde actually took the measurements as it ascended. An upper limit can be placed using the standard radio atmosphere since this corresponds to weak super-refraction when steep gradients are less likely to occur. The two extreme cases are also important: near-zero temperature gradient when steep humidity lapses can form, and near-zero humidity lapses when steep temperature gradients form. In the first case the limit is taken to be the standard atmosphere with linear variation either side while for the second the critical gradients are used. No comment need be made on the subjective nature of this area, and it cannot be taken as anything more than a guide until further evidence is available.

(b) The analysis of ducting conditions is obtained by reading temperature gradients (degrees Celsius per millibar) and humidity gradients (gram per kilogram per millibar) from radiosonde ascents in and around the area where forecasts are required. The graph (Figure 1) is then used to determine whether the combination of temperature and humidity gradients will cause ducting, no ducting, or partial ducting.

It is also important to note the height above sea level of inversions, since low-level inversions are more likely to cause ducting than are high-level inversions, whilst those above 4000 m can normally be disregarded unless the radio transmitter is sighted on a high plateau.

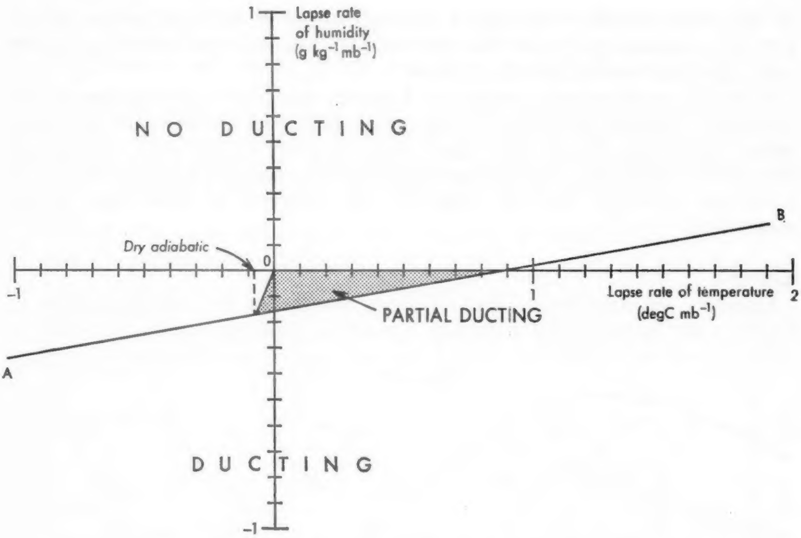

FIGURE 1—GRAPH USED TO DETERMINE WHETHER THE ENVIRONMENT MEASURED BY A RADIOSONDE ASCENT WILL CAUSE DUCTING

The line AB separating 'ducting' from 'no ducting' is inequality (4), with the critical gradients corresponding to the standard radio atmosphere. The area of 'partial ducting' is an attempt to allow for the inadequacies of radiosonde ascents (see text). The graph should not be used for pressures below 700 mb.

(c) Forecasts of ducting can then be made using the numerical estimates together with the meteorological ideas stated above. If cloudless weather with light winds is expected during the forecast period then ducting should be forecast in association with the nocturnal surface inversion and the day-time sea-breeze. The only real problems here would be the timing of onset and cessation. Ducting in the sea-breeze occurs soon after the sea air has penetrated inland and then becomes weaker as the circulation dies away in the evening. The onset of ducting with the nocturnal inversion obviously depends upon how quickly the layer of cold air near the ground builds up and ducting will only be important when the steep temperature gradients are above the level of the transmitter. This could be several hours after sunset for tall masts. After dawn ducting will still be present until the inversion has been destroyed by solar heating. Other factors, such as an increase in surface wind, or cloud cover, would also have to be considered if they were to affect the sea-breeze or inversion.

Subsidence inversions below 4000 m are best related to the trough/ridge pattern at 850 and 700 mb. Prognostic charts at these levels are then used to determine the forecast trough or ridge positions and hence to forecast the extent of subsidence inversions. Building ridges or highs are especially important since the height of the subsidence inversion is likely to become lower and cause more marked ducting. When radiosonde data are sparse, some idea

of the lateral extent of subsidence inversions may be obtained by use of the thermal advection pattern at 850 and 700 mb. Marked cold advection implies subsidence and warm advection ascent.

Mountain ranges could complicate forecasts should the requirement be for ducting in a specific direction. A nocturnal surface inversion is normally well below the mountain tops and radio waves trapped in this duct will not go beyond the mountains. Subsidence-inversion ducts may allow propagation over mountains provided that the height of the inversion is above that of the mountains.

Example

Consider the hypothetical 850-mb chart for the eastern Mediterranean in Figure 2 and suppose that a ducting forecast is required at point A, which is

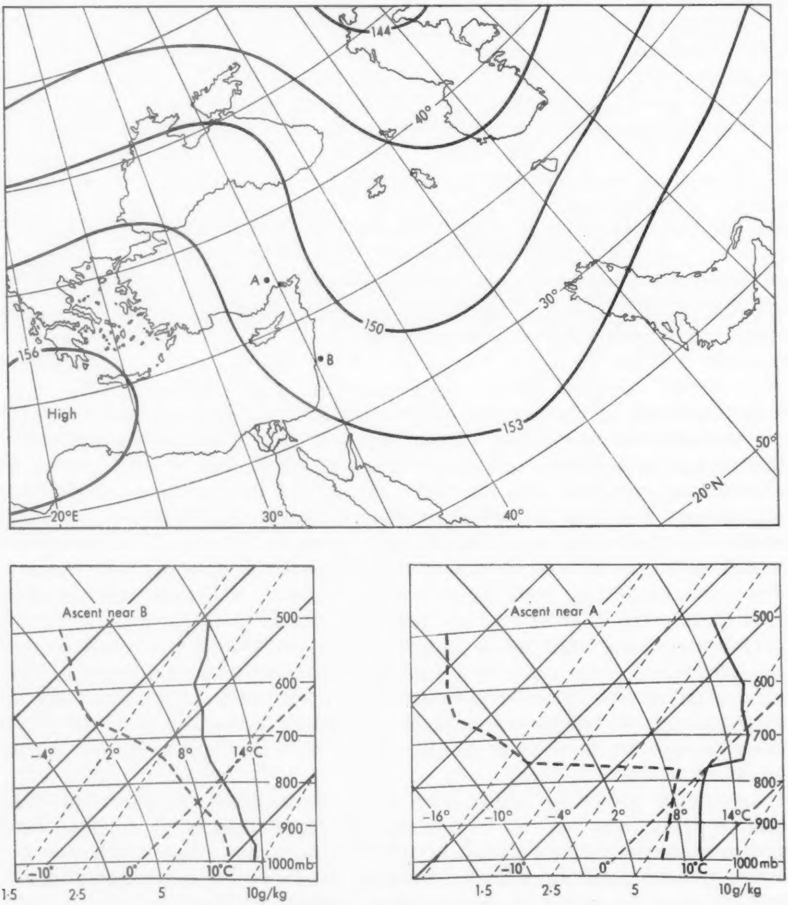

FIGURE 2—HYPOTHETICAL 850-mb CHART FOR 00 GMT ON 22 APRIL

a station 2500 m above mean sea level, and at point B, which is a coastal site, but with mountains rising to 1700 m, 16 km inland.

Representative radiosonde ascents are shown in the ridge and trough.

(1) *Analysis at 00 GMT on 22 April.* Marked subsidence inversion in the ridge over Turkey, but station A is above the level of this inversion. Point B is in the trough, the ascent is unstable and the weather is partly cloudy with showers. Ducting is expected in the ridge, but not in the trough.

(2) *Forecast until 00 GMT on 23 April, issued at 06 GMT on 22 April.* The 850-mb prognostic chart for 12 GMT on 22 April (Figure 3) shows that the trough or ridge system has moved south-eastwards and by that time the subsidence inversion should be starting to affect B. The forecast for B should mention ducting in association with this inversion, beginning at 12 GMT and continuing for the next 12 hours.

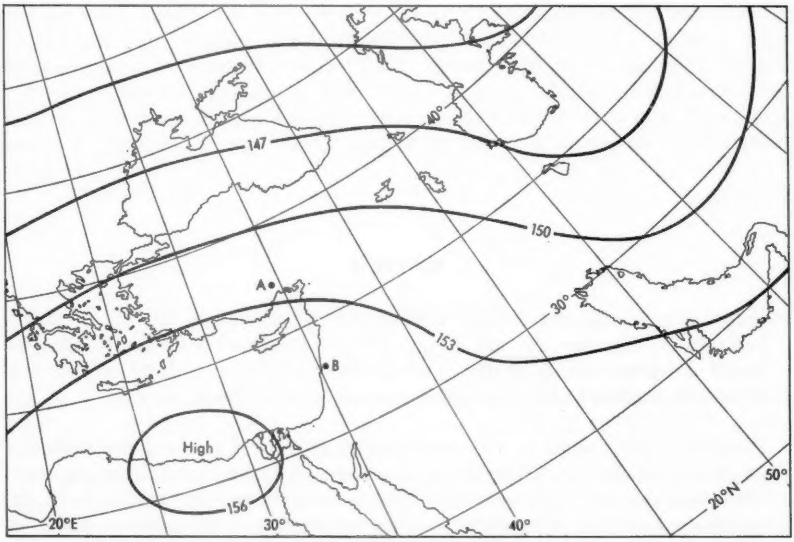

FIGURE 3—HYPOTHETICAL PROGNOSTIC CHART FOR 850 mb FOR 12 GMT ON 22 APRIL

In addition, considerable heating inland is expected during the day in April when the cloud associated with the trough has moved away. The cloud could be expected to delay the onset of a sea-breeze and ducting associated with it should be forecast for the afternoon. Some mention should also be made that the most pronounced ducting will be parallel with the coast, but no more than 16 km inland. No ducting is expected at A during the period. However, if A were in a high-level valley ducting in the nocturnal valley inversion should be mentioned for the last few hours of the forecast period, provided that the sky remains clear and the winds light.

Conclusion

This method could be used by forecasting offices outside the Mediterranean area, since the principles apply anywhere. The full procedure takes about 30 minutes, but a quick assessment could be made from inspection of tephigrams by assuming that all isothermal layers and inversions below 4000 m are associated with ducting.

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REVIEW

Propagation of visible and infrared radiation in the atmosphere, by V. E. Zuev. 240 mm × 160 mm, pp. xii + 405, *illus.*, (translated from the Russian by Israel Program for Scientific Translations, Jerusalem), John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1974. Price: £13.25.

Professor Zuev's work in the experimental aspects of atmospheric radiative transfer are well known. Recently he has been concerned with the application of radiation theory to the absorption and scattering of laser radiation in the atmosphere, and this comprehensive monograph reflects his research activities and interests. In this way the book serves as a good background for understanding and describing the propagation of laser beams in the atmosphere.

The book consists of three parts. The first part discusses the questions of absorption of visible and infra-red radiation from thermal sources and lasers under various atmospheric conditions. The physical origin of the absorption spectra of atmospheric gases and the analytical description of the absorption are well presented. In this way the discussions are classical. But there is no mention of the basic photochemical reactions of the upper atmosphere. While the abundances of the important minor gases O_3, O_2, CH_4, N_2O, CO etc. are discussed, the possibility of variability of these species is not considered. Neither is there any discussion of the water-vapour dimer model, which we now know to be very important in the continuum absorption in the 8–13-μm region.

The second part of the book presents a study of the aerosol and molecular scattering of visible and infra-red radiation, and thermal sources and optical lasers are considered under different atmospheric conditions. The single scattering characteristics are well covered, but the discussions of multiple scattering by cloud and aerosol particles are poor by present western standards. The Russian school still favours the analytical approach which can treat only the most simplified situations. The numerical techniques for multiple scattering developed during the last decade were available in the literature before the publication of the original Russian edition, and should have been included.

The third part of the book comprises a systematic examination of various aspects of the propagation of radiation beams from lasers and thermal sources in the atmosphere. The basic radiation parameters of different types of laser are considered and the results analysed which concern the structure of the light field in the cross-section of a beam propagating through various scattering media. The effect of turbulent atmospheric motions on the propagation of laser beams is also discussed.

The book suffers in parts from the rapid developments in atmospheric physics since the original Russian book was published in 1970. However, the monograph does contain many tables, figures and a bibliography of 910 entries, primarily Russian, which ideally support the presentation of the theory. The book should therefore be a useful research text to students and research workers in the theory and application of atmospheric radiation transfer.

G. E. HUNT

NOTES AND NEWS

Retirement of Mr E. Evans

On 24 November 1975 Mr Eric Evans retired from the Meteorological Office after a career of 37 years spent largely in the service of the Royal Air Force in a variety of posts at home and overseas.

After studying at the University College of Swansea, where he took the degrees of B.Sc. in 1936 and M.Sc. in 1938, Mr Evans left his native Wales to join the Office as a Technical Officer. Following his training at South Kensington, he went to Wyton as a forecaster. In 1942 he was transferred to High Wycombe as a liaison officer with the United States Army Air Force and was commissioned as Flight Lieutenant in 1943. In 1945 he moved to Transport Command and was detached to Australia for liaison duties as a Squadron Leader.

After demobilization in 1946 Mr Evans was detached as a Senior Scientific Officer to New Zealand for a short time before settling down as a forecaster at Overseas Aircraft Control, Gloucester, for nearly five years. In July 1950 he went overseas again to take charge of the forecasting office at Negombo, Ceylon. From there he moved to Headquarters Near East Air Force at Singapore early in 1952 with promotion to Principal Scientific Officer, and included a short detachment to Iwakuni, Japan, before returning to the United Kingdom at the end of 1953.

The next four years saw him in charge of main meteorological offices, first at Headquarters No. 3 Group, Mildenhall, and then back at Gloucester. His next assignment was to Meteorological Office Headquarers at Victory House where he spent three years in the Defence and International Branch, with special responsibility for NATO affairs. This was followed by a two-and-a-half-year tour of duty back in uniform, this time as a Group Captain at Supreme Headquarters Allied Powers in Europe, Paris.

After his return to the United Kingdom in 1962, Mr Evans spent the next four years at Bracknell as a Senior Forecaster in the Central Forecasting Office. He then went to High Wycombe for nine months as Deputy Chief Meterological Officer at Headquarters Bomber Command before returning to Bracknell for four years in the Defence Services Branch with responsibility for meteorological offices overseas. On 30 December 1970 he was promoted to Senior Principal Scientific Officer and returned to High Wycombe as Chief Meteorological Officer, Headquarters Strike Command. His last posting was back to Bracknell as Assistant Director (Defence Services).

Eric Evans will be remembered for his considerate dealings with staff and a forthright approach to practical problems, to say nothing of his partisan support for Welsh sport. His many friends will wish Eric and his wife a long and happy retirement, with plenty of time to tour the country in their caravan.

M. H. FREEMAN

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CONTENTS

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

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